

STATISTICAL STUDY OF NOCTILUCENT CLOUD OCCURRENCE IN WESTERN EUROPE

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Abstract: Amateur reports of noctilucent cloud (NLC) displays during 1964 to 1992 in north-west Europe are analyzed. A 5-day variation in occurrence of bright NLC has already been noted in the same reports during 1964 to 1982 by M. GADSDEN (Ann. Geophys., **3**, 119, 1985). In this paper the 5 to 6-day periodicity is confirmed to be even more pronounced if negative reports (clear night with no NLC) are taken into account in statistical analysis. This result stresses that the periodicity is not due to weather conditions but it reflects the intrinsic nature of NLC formation. The cause of 5 to 6-day periodicity is discussed, whether it is due to planetary waves in the mesosphere or due to the *in situ* origin of NLCs, ionic nucleation of ice particles. To see long-term trends of NLC occurrences a requirement for objective recording of NLCs by equipment such as CCD cameras in both polar regions is suggested.

1. Amateur Observations of NLC

During summer around midnight in the northern sky, over Oslo or Stockholm, one can occasionally observe bright silver blue clouds. These are noctilucent clouds (NLCs) which scatter sunlight at the altitude of about 82 km, they are the highest clouds in the Earth's atmosphere. Like diamond dusts on a cold mountain, water vapor condenses directly into solid ice in the cold summer mesopause.

GADSDEN (1985) found 5-day variations in bright NLC occurrence in amateur reports from 1964 to 1982. At present long-term NLC observations from the ground are performed only by amateur watchers. The reason for the lack of professional ground-based observers is in short as follows (GADSDEN and SCHRÖDER, 1989):

Bright cloud appears intermittently once in about 5 days, 3 nights being clear per a week, then bright NLCs are observed only 4 days during 100 days in a summer:

$$100 \text{ days} \times \frac{1}{5} \times \frac{3}{7} \times \frac{1}{2} \approx 4 \text{ days}, \quad (1)$$

where $1/2$ is a probability for NLC to be bright enough. As the dark sky lasts only 4 hours in the neighboring region of white night, so the observational time for bright NLCs is only 16 hours per a year. This is not an attractive prospect for an employer or a funding agency.

Recently SUGIYAMA *et al.* (1996) found a 5.5-day periodicity in polar mesospheric summer echoes (PMSEs) observed with the Poker Flat VHF radar in Alaska during 1980 to 1984. PMSEs occur around 84 km in height at the polar regions in the same season as that of NLCs (RÖTTGER, 1995). Similar periodicity thus found in both NLCs

and PMSEs strongly suggests their close relationship. GADSDEN (1985) speculated the cause of the periodic variation of NLCs as due to planetary waves. On the other hand, SUGIYAMA (1994) showed in his numerical simulations that NLCs will occur periodically in the case that their origin is proton-hydrates $\text{H}^+(\text{H}_2\text{O})_n$. At any rate, further investigation into the periodicity is required. In this paper amateur NLC reports extending from 1964 to 1992 are examined.

2. Statistics of NLC Occurrence

Reports of amateur observations are edited by the meteorological agency of UK, and are listed in *Meteorological Magazine*, its publication has unfortunately been discontinued in 1994. In the lists, more than 70% of reports are from UK, others are from Netherlands, Finland, occasionally Russia, and more rarely from Greenland or from Alaska. There is much missing data primarily owing to weather conditions. As the clouds are mainly observed with naked eyes and sometimes with photographs, NLCs are identified through the observed time to be midnight, colors in silver blue, and particular shapes in cloud structures due to turbulence and gravity waves which are dominating in the mesopause. In old reports there was information about wind velocities estimated from advection of NLCs, which was a historical method to observe mesospheric circulations.

We analyze NLC lists during 29 years from 1964 to 1992 (PATON, 1965–1973; MACINTOSH and HALLISSEY, 1974–1982; GAVINE, 1984–1993). In the lists brightness of NLCs is described merely qualitatively for which we put numeric values in Fig. 1 as follows: <very bright> is assigned to be 4, <bright> as 3, with <medium brightness> as 2, <faint> or unclassified as 1, missing data as 0, faint or unclassified report from only one station as -1 , negative report (clear night with no NLCs) as -2 . The most significant feature seen in Fig. 1 is that NLCs occur quite intermittently, enduring only a few days at most. Negative reports are important information to see whether the intermittency is due to weather conditions in the lower atmosphere or due to the intrinsic nature of NLC formation. As shown in Fig. 1, unfortunately, negative reports were not included in the lists during a period of 1973–1982.

Figure 2 shows yearly variations of positive nights for NLC displays. Analysing amateur reports during 1964 to 1988, GADSDEN (1990) have discussed on the yearly trends of NLC displays that; 1) the years with fewest NLCs are found typically two years after solar maximum. 2) After a correction of the solar activity dependence, NLC displays show double increment from 1960's to the end of 1980's, suggesting a result of global warming which cools the mesosphere like an excellent heat-trapping blanket which has cooler surface than ordinary one. He is inferring the decrease of occurrence in 1990–1992 (Figs. 1 and 2) as due to eruption of Pinatubo volcano (GADSDEN, private communication, 1996). For a further investigation concerning global warming, a long-term project is necessary to record images of twilight sky at various stations near the polar regions using equipment such as CCD cameras in all weather conditions.

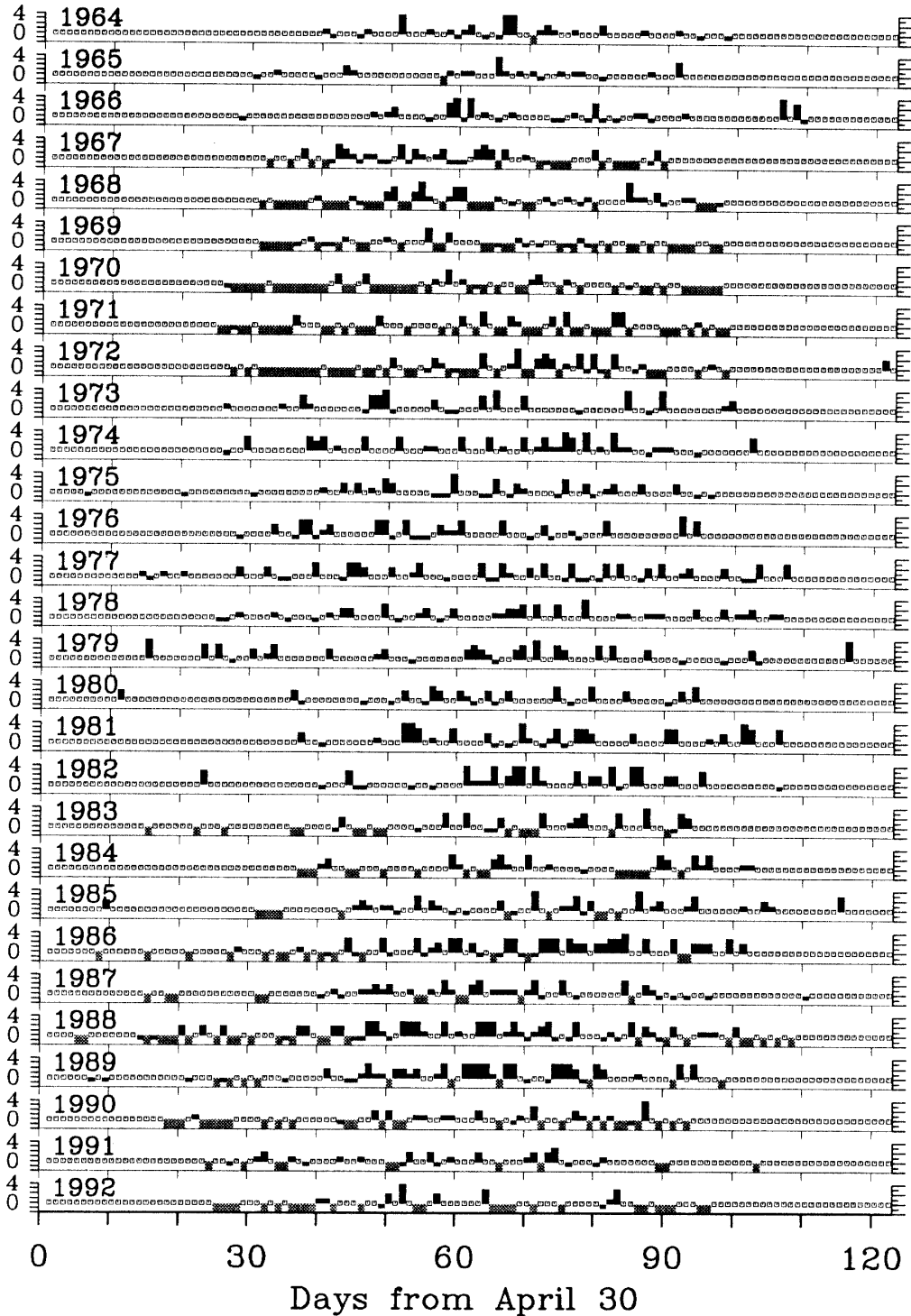


Fig. 1. NLC reports by amateur observers from north-west Europe during 1964–1992. Lists of reports are from *Meteorological Magazine*. Brightness are ranked from 4 to 1 according to very bright, bright, medium, faint and unclassified. Faint report from only one station is labeled as -1 , negative report as -2 . Square at 0 level shows missing data (see text).

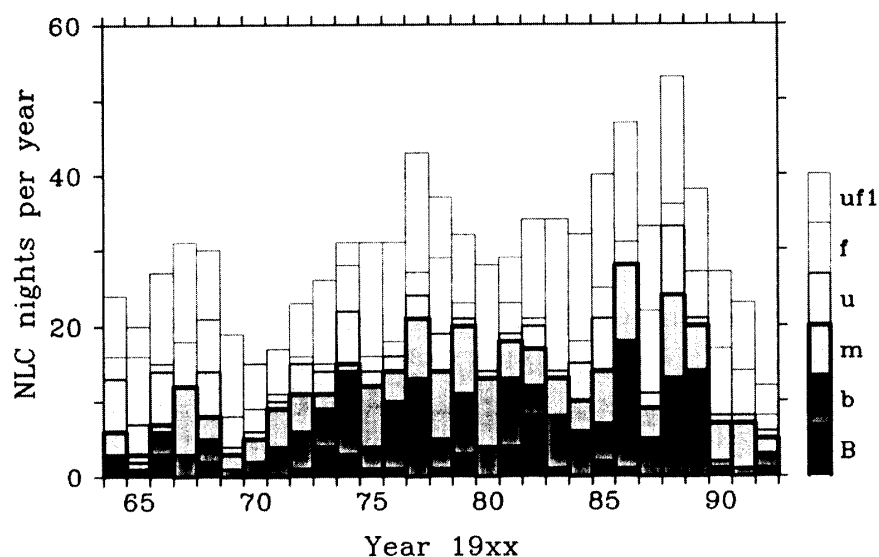


Fig. 2. Yearly variation of positive nights for NLC. *B*=very bright, *b*=bright, *m*=medium, *u*=unclassified, *f*=faint, *uf1*=faint and unclassified report from only one station.

3. Periodicity in NLC Occurrence

Figure 3 shows results of periodic analysis in NLC occurrence. Number of NLC nights against an interval of preceding NLC night is shown in Fig. 3a where 356 positive nights are examined with NLCs brighter than <medium>. We see in Fig. 3a, although weak, a 5-day periodicity, which confirms the result of GADSDEN (1985). In

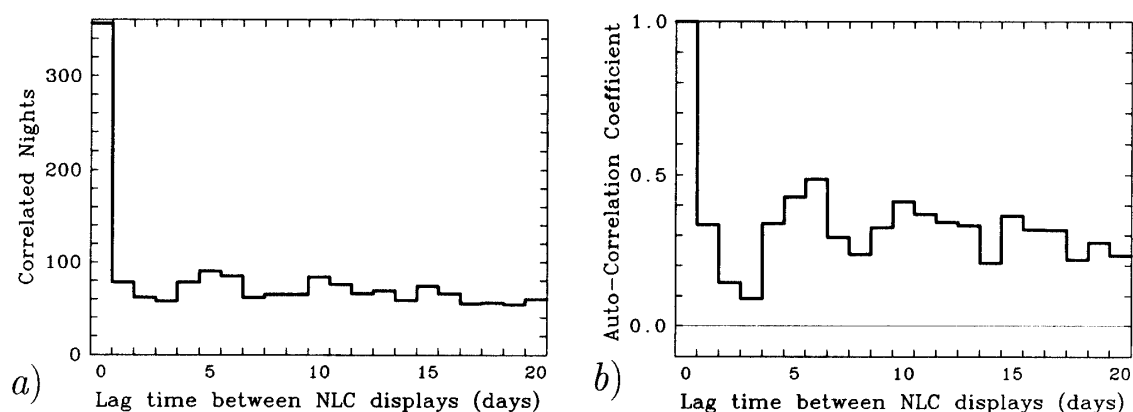


Fig. 3. a) Autocorrelation of bright NLC occurrence of 356 nights during 1964 to 1992. Putting 1 for NLC nights with brightness greater than medium, all other nights are set as missing data which are excluded in calculation. b) Same as Fig. 3a but including negative night with a numeric value of -1 . Total negative nights are 307. Calculated summer term in each year is from 4 days before the first NLC display to 4 days after the last NLC.

addition to the data used in Fig. 3a, negative reports are applied in Fig. 3b. In Fig. 3b, positive NLC nights with brightness greater than <medium> are put to be 1, negative nights to be -1 , and all other nights are treated as missing nights, *i.e.*, in an autocorrelation function we added a correlation values only when both nights in a pair of a given lag time are not missing nights. Apparently the periodicity around 5 to 6 days is much more stressed in Fig. 3b than in Fig. 3a, which stresses that the periodicity of NLC displays is not due to weather conditions but reflects some intrinsic nature of NLC formation. Cause of the periodicity is discussed in the following sections.

4. Comparison with PMSE Observations

As for the echoing mechanism, occurrence of PMSEs due to charged ice particles is discussed (see CHO and KELLEY, 1993). SUGIYAMA *et al.* (1996) found 5.5-day periodicity in echo intensities of PMSEs observed during 1980 to 84 with Poker Flat radar in Alaska. Note that the radar observed mesopause primarily throughout 24 hours a day continuously in all weather conditions. Periodic formation of NLCs as shown in Fig. 3b confirms similarity of the period and thus intimate relationship between NLCs and PMSEs.

GADSDEN (1985) considered the 5-day variation of NLCs as due to planetary waves. Planetary waves are identified in the upper atmosphere during the summer season at least up to the upper stratosphere (HIROTA and HIROOKA, 1984). However, in the mesospheric velocity fields associated with PMSEs over Poker Flat, any notable oscillations in a period around 5.5 days were not found (SUGIYAMA *et al.*, 1996). Further investigations are required whether planetary waves in a period of 5 days are dominant in the polar summer mesopause or not.

5. Discussion

Interpretation of 5 to 6-day periodicity in NLCs alternative due to planetary waves is that NLC has an *in situ* origin. Up to now the major origin of NLC is thought to be fine particles called “meteoric smoke” recondensed at the injection burning of meteors into the mesosphere (HUNTEN *et al.*, 1980; TURCO *et al.*, 1982), but in this case oscillatory cloud formation occurs only when meteoric smoke is supplied periodically. In the case of *in situ* origin of a cloud, oscillation of NLC formation is considered to be general as below (SUGIYAMA, 1994).

In the mesosphere ionic reactions with ambient molecules convert major positive ion of NO^+ into proton-hydrate(PH) $\text{H}^+(\text{H}_2\text{O})_n$, and PH grows heavy one through succeeding hydrations. Due to the short life time of PHs caused by frequent recombination with electrons, PHs with n only up to 20 have so far been observed by rocket measurements (BJÖRG and ARNOLD, 1981). Even though heavy PHs with n greater than, *e.g.*, 70 are quite small in amount, they will be converted steadily into $(\text{H}_2\text{O})_{n-m}$ at the cost of partial evaporation of m water molecules ($m \approx 30$) at recombination. In a condition of supersaturated humidity, production of PHs with n ligands depends on n -th order of powers of saturation ratio, *i.e.*, quite sensitive to humidity. Because fur-

ther growth of ice particles consumes large amount of water vapor in the course of descent (over a day), an excess production of heavy PHs brings about “freeze-drying” in the mesopause which, in turn, suspends further production of heavy PHs. Cloud formation restarts when water vapor from the bottom of the cloud reaches the mesopause in a delay of diffusion time due to mesospheric eddy mixing. If the diffusion time is much shorter than the consumption time of water vapor, steady formation of cloud occurs, which is the case in dry mesopause where ice particles are quite small in number and must be invisible. On the contrary, in wet mesopause oscillatory formation of NLCs occurs due to excess production of PHs. I believe that the oscillatory formation must be a unique way for NLCs to be visible in such a rarefied atmosphere as in the mesopause.

This oscillation of NLC caused by phase changes of material is quite similar to a thermodynamical toy called “drinking bird”, which was invented at Hiroshima just after World War II and named “HEIWA DORI”, meaning a “peace bird” in Japanese.

6. Conclusion

A 5 to 6-day periodicity is confirmed in the bright NLC occurrence observed in north-west Europe during 1964 to 1992. Statistics including negative reports, clear night with no NLCs, stresses the periodicity, which shows the oscillation is the characteristics of NLC formation. Further observations of NLC occurrences, especially in long-term recording with, *e.g.*, CCD imagers are suggested in the wide regions near the polar white night in order to investigate global change as well as the origin of NLCs.

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